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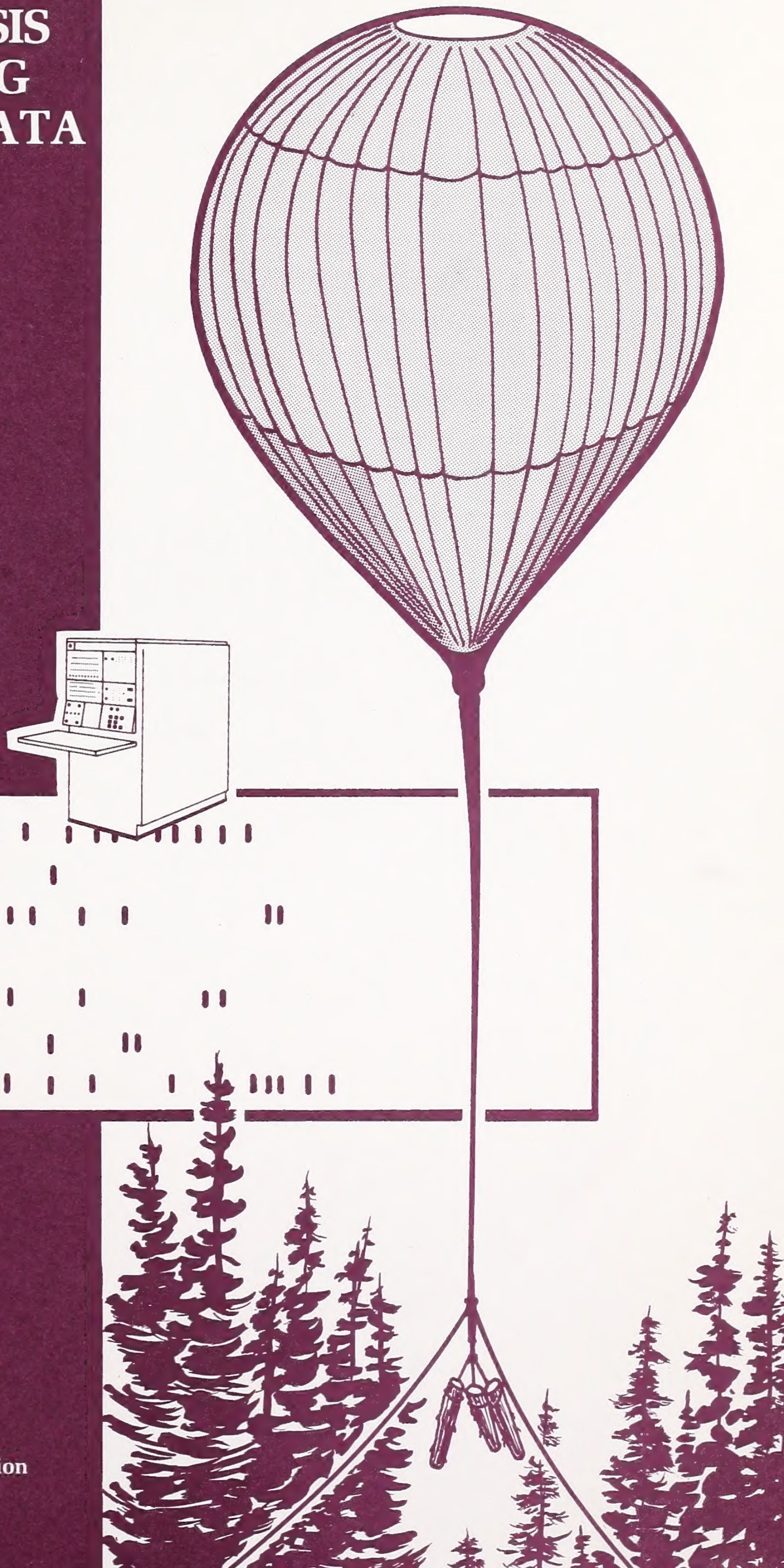

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THE AUTHORS

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RESEARCH SUMMARY

Time and motion studies were conducted on an experimental balloon logging show in the Idaho batholith during 1973. The objective of the study was to determine the variables affecting production and to develop models for estimating production rates. A data collection technique and a method of statistical analysis are presented for others involved in analyzing balloon logging operations.

Selected variables were divided into three classes: those involving the time required for each portion of the logging cycle (dependent variables), factors directly related to the yarding operation (independent variables), and coded independent variables (such as surface type and condition, operator skill, and landing size).

Variables were then partitioned into four groups so that easy comparisons could be made between predictive models. A statistical program was used to determine and quantify the most important variables for each model. The resulting regression equations serve as limited guidelines for predicting time requirements for the various portions of the balloon logging cycle and identify factors that have a significant influence on this cycle.

CONTENTS

INTRODUCTION

Flying logs from the stump to a landing area using a balloon is a relatively new technique to minimize the environmental impacts of logging. Little data are available on balloon logging production and the factors affecting production rates.

This report presents the results of a 1973 time and motion study of a balloon logging experiment in the Idaho Batholith. The results may be useful for foresters or engineers estimating logging production rates, and for analyzing proposed balloon logging operations. A data collection technique, a method of statistical analysis, and the relative importance of different measured variables involved in balloon logging studies are presented. These should help avoid the wasted time and effort which normally occur when starting a study on any new logging system. It must be recognized that these results are narrow in scope when one examines the wide range of variables possible in terrain conditions, timber harvesting techniques, climate, logging set configurations, volume of timber per acre, and log size, to mention a few.

Details of the balloon logging system, timber harvest prescription, terrain conditions, environmental constraints, and cost data are described in Forest Service Research Paper INT-208, "Balloon Logging in the Idaho Batholith: A Feasibility Study," by William S. Hartsog (1978). The paper provides valuable information on the functioning of the balloon logging system, information necessary for understanding the applicability of time and motion data.

METHODS

The first task of the time and motion study was to observe carefully the balloon system operation and factors affecting production rates. Selection of variables to be measured during the data collection phase was based on these observations. Time required to complete a logging cycle (turn) was determined to be the dependent variable since it indicated production and seemed to be affected by many of the other factors. Turn time was partitioned into five elements. Since total turn time equaled the sum of these five elements, all six are dependent variables. The dependent variables are fully defined, along with the independent variables, in a later section.

Data Sheets

Data sheets were designed to collect information on those factors selected in the initial observations; these were to serve as variables in a multiple regression analysis. Three data sheets were used for collecting field data: Site/Terrain Information, Yarding Data, and Scaling Data. The Site/Terrain Information sheets (fig. 1) were used to record information pertinent to site description, site conditions, and the logging subsystem (balloon yarding in this case). Yarding Data sheets (fig. 2) were used to record the time required for each element within the turn and other physical measurements important to the study. Scaling Data sheets (fig. 3) were used to record the measurements of each log so that volume and weight could be calculated for each turn of the ballon yarding subsystem. For a detailed description of the data collection methods, see the publication "Time Study Techniques for Logging Systems Analysis" (Gibson and Rodenberg 1975).

SITE/TERRAIN INFORMATION FORM

SITE DESCRIPTION

Logmaking ________ Location
Skidding ________ Timber Sale ________
Yarding *102* Forest *Boise, Garden Valley R.D.*
Loading ________ Type of Cut *Overstory*
Hauling ________ Contractor *Boise Cascade*
Data Collection Date *7/11/73* Start Time *7:00 a.m.* Stop Time *12:00*

Comments *Broken Gear in Planetary*

SITE CONDITIONS

	Rating				
Surface Type	1	2	3	4	Comments *very brushy*
Surface Condition	1	2	3		Comments
Operator	1	2	3		Comments
Landing	1	2	3	4	Comments *gusty winds & small landing*
Deck	1	2	3	4	Comments

Temperature *75* degrees Elevation *map* feet
Wind *5* velocity *S.W.* direction Precipitation *0* inches ________ form

SUBSYSTEM INFORMATION

Logmaking Comments ________
Crew Members
________, Comments ________
________, Comments ________
Saw or Feller
Make ________ Type ________ Equipment Owner ________
Model ________ Size ________ Payment (Method & Amount) ________

Skidding/Yarding Comments ________
Crew Members
operator, foreman, Comments ________
headrigger, unhooker, Comments ________
2 hookers, knot bumper, Comments ________
Skidder or Yarder
Make *Washington* Type ________ Equipment Owner *Boise Cascade*
Model *608 Aero* Size ________ Payment (Method & Amount) ________

Loading Comments ________
Crew Members
________, Comments ________
________, Comments ________
Loader
Make ________ Type ________ Equipment Owner ________
Model ________ Size ________ Payment (Method & Amount) ________

Hauling Comments ________
Crew Members
________, Comments ________
________, Comments ________
Truck and Trailer
Make ________ Type ________ Equipment Owner ________
Model ________ Size ________ Payment (Method & Amount) ________

Figure 1.--Site/terrain information form.

YARDING DATA – TURN ELEMENT TIME STUDY FORM AND KEYPUNCH TRANSCRIBING FORM
Snapback Reading

SUBSYSTEM	EQUIPMENT & METHOD	CODE NO.	TURN NO.	1 TRAV. UN.	2 TRAV. LAT.	3 HOOK CH.	4 TRAV. LOAD.	5 UN-HOOK CH.	FOREIGN ELEMENT			DIST. (FT)	SLOPE (%)	LAT. DI. (FT)	NO. OF LOGS	SPECIES	MVR (MBF/A)	TREES/ACRE (TENS)	TCV (FT^3/A)	SURFACE T.	SURFACE C.	OPERATOR	LANDING	DECK	I. D.	ADDITIONAL DATA	CONTINUE
1	2 3	4 5 6	7 8 9	10 11 12	13 14 15	16 17 18	19 20 21	22 23 24	25 26	27 28 29	30 31 32	33 34 35 36	37 38 39 40	41 42	43 44	45	46 47	48 49 50	51 52	53	54	55	56	57	58	59–79	80
3	60	102	1	1.9	2.3	2.5	5.8	1.0				1200	-65	99	2	2				3	1	2	3	1			
			2	2.9	2.3	3.8	5.3	1.5	24	1.3	1.4	1200	-65	99	3	2											
			3	1.1	1.0	3.7	3.5	.5	25	.5	1.2	1000	-65	15	3	2											
			4	1.3	2.4	3.4	3.9	1.0				1000	-65	70	3	3											
			5	1.3	1.4	2.0	2.0	.8				1000	-65	70	3	2											
			6	.9	.4	2.3	2.4	1.1				1000	-65	20	3	3											
			7	1.7	1.1	.9	2.7	.7				1000	-65	60	4	3											
			8	1.7	1.0	.9	2.6	.4				1000	-65	70	3	3											
			9	2.9	.9	1.7	2.8	1.0				1000	-65	50	3	3											
			10	1.5	1.4	1.3	1.6	1.0				800	-65	40	1	2											
			11	1.4	.9	4.2	1.5	.5				800	-65	40	2	3											
			12	1.5	.8	1.3	4.0	.2				800	-65	50	3	3											
			13	1.8	1.0	1.2	1.9	1.5	25	.8	1.0	700	-65	40	4	3											
			14	1.6	1.2	2.4	1.9	.9				600	-65	20	3	3											
			15	1.9	.9	1.3	2.2	.5	24	1.0	.9	600	-65	30	2	3											
			16	2.3	1.0	1.1	2.3	.3				600	-65	30	3	3											
			17	1.3	1.1	.9	1.3	1.0				600	-65	40	4	3											
			18	1.1	.9	.8	1.5	.6				600	-65	40	1	3											
			19	1.3	.9	1.7	2.4	.4	25	52.4	1.2	500	-65	40	3	3											
			20	1.7	1.5	2.0	3.4	.4				400	-65	40	3	2											
			21	2.4	2.1	2.9	2.0	.7	23	2.5	4.6	400	-65	75	4	3											
			22	1.7	2.2	3.2			34	.0		400	-65	60	0	-											
			22						31	.0	99.0																

Figure 2.--Yarding data sheet.

SCALING DATA

DATE 7/11

MATCH WITH TIME STUDY FORM CODES 101, 102, ______

CODE NO.	TURN NO.	NO. OF LOGS	LOG 1			LOG 2			LOG 3			LOG 4			LOG 5			LOG 6			LOG 7			LOG 8			LOG 9			LOG 10			LOG 11			LOG 12		
			D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L
102	1	2	8	20	33	20	22	24																														
	2	3	10	22	33	10	20	24	20	22	16																											
	3	3	10	12	33	10	18	33	12	20	33																											
	4	3	8	12	33	10	16	24	16	24	29																											
	5	3	8	16	14	18	18	18	24	28	25																											
	6	3	20	24	39	12	14	33	10	12	33																											
	7	4	8	12	20	12	18	24	12	16	33	10	12	37																								
	8	3	8	12	24	8	12	24	12	20	33																											
	9	3	8	20	31	8	12	33	12	20	24																											
	10	1	28	30	8																																	
	11	2	8	10	25	24	36	20																														
	12	3	10	16	35	8	12	35	20	24	33																											
	13	4	8	14	35	8	16	35	8	14	33	10	14	29																								
	14	3	14	24	35	10	20	33	10	22	33																											
	15	2	10	12	10	10	16	20																														
	16	3	10	20	39	10	24	39	12	14	33																											
	17	4	14	20	33	10	12	33	16	20	33	8	12	33																								
	18	1	10	14	25																																	
	19	3	16	20	33	16	18	33	8	12	25																											
	20	3	22	24	16	16	18	33	18	22	33																											
	21	4	12	18	25	18	24	25	12	24	35	12	16	33																								
	22																																					
	23																																					
	24																																					

Figure 3.--Scaling data sheet.

Definition of Variables

Variables were divided into three classes: dependent variables (measurements of time), independent variables (factors directly related to the operation of the yarding subsystem), and coded independent variables (qualitative independent variables with only a few levels). The dependent variables were defined as follows (the abbreviation following the variable will be used throughout this report):

1. Travel unloaded (TU).--Time, in minutes, required for the balloon to travel from the log landing area to the general area of the felled logs.

2. Travel laterally out (TLO).--Time, in minutes, required for the choker setter to drag the tagline from a point directly beneath where the balloon stopped to the felled logs.

3. Hook chokers (HC).--Time, in minutes, required for the choker setter to hook the tagline to the preset chokers and scramble clear of the travel path of the logs.

4. Travel loaded (TL).--Time, in minutes, required for the yarder to yard the load of logs and place them on the landing.

5. Unhook chokers (UC).--Time, in minutes, required to unhook the chokers.

6. Total turn time (TT).--Total time, in minutes, for one complete logging cycle (TT = TU + TLO + HC + TL + UC).

The first five dependent variables are the elements from which component models were constructed. The sixth variable, total turn time (TT), is the dependent variable used in the model for predicting the time required to complete a logging cycle.

Measurements of time were also taken on foreign elements, delays in the logging cycle due to an event which was not a normal occurrence during the yarding operation. Foreign elements were not included in the analysis as they proved to be random.

The independent variables were defined as follows (the abbreviation following the variable will be used throughout this report):

1. Number of logs (NL).--Total number of logs carried on each turn.

2. Volume (VOL).--Volume, in board feet (Scribner scale), of the logs carried on each turn.

3. Weight (WT).--Weight, in pounds, calculated from measurements of the logs carried on each turn.

4. Distance (DI).--Slope distance (along the ground surface), in feet, from the landing area to where the balloon stopped to pick up a load of logs.

5. Slope (SLO).--A decimal number defined as the vertical distance from the yarder to the logs, divided by the horizontal distance from the yarder to the logs (slope is positive for yarding downhill and negative for yarding uphill).

6. Lateral distance (LDI).--The lateral distance, in feet, from where the tagline touched the ground to the choker on the felled logs.

7. Lateral slope (LSLO).--A decimal number determined by the vertical distance from the ground beneath the tagline to the logs, divided by the horizontal distance from the tagline to the logs.

8. Temperature (TEMP).--The highest daily temperature (°F) taken while the yarding crew was working.

9. Wind velocity (WINVEL).--The highest daily wind velocity (mi/h) taken while the yarding crew was working.

Measurements were also taken on precipitation but most of the measurements were zero or trace levels so this provided little useful information.

The coded independent variables were defined as follows:

1. Surface type.--Coded from one (little surface obstruction) to three (severe surface obstruction).

2. Surface condition.--Coded from one (dry, firm soil) to three (wet, muddy soil).

3. Operator.--Coded from one (below average) to three (above average).

4. Landing.--Coded from one (spacious landing) to three (limited landing).

5. Deck.--Coded from one (easy to land logs and unhook chokers) to three (difficult to land logs and unhook chokers). A four indicates this variable was not applicable

A more complete description of the criteria for the classification system is contained in Gibson and Rodenberg (1975).

ANALYSIS

Model building was partitioned into four classes so that easy comparisons could be made. The first class was composed of the independent variables, except TEMP and WINVEL. The second class also was composed of the independent variables, except TEMP and WINVEL, but interactions were allowed. The third was composed of all the independent variables. The fourth class was composed of all the independent variables plus interactions. These four classes were then used to compare the simple models (no interaction terms) and the interaction models since the physical constraints of the system implied that most of the independent variables were linear. The effect of TEMP and WINVEL was analyzed separately since there were a few levels (many repeated values) of these two variables; estimates were based on only a few unique observations. TEMP and WINVEL were included in the final analysis, but their contribution to the regressions was weak since there were only a few levels of each variable.

The coded independent variables were eliminated from the final model building because no significant correlations with the dependent variables were found. Analysis using graphs and dummy variables indicated there was not enough range in the observations at each level to meaningfully measure the association between the coded independent and dependent variables. The analysis and field observations also indicated a need for a more quantitative method of rating the coded variables. The authors defined the coded variables in this report because they could be important on other logging studies if the variable levels were better defined and the range of conditions was sufficiently large.

The four classes of models were used to form predictive equations for TT and for the components TU, TLO, HC, TL, and UC. A statistical program, BMD02R from the U.C.L.A. Biomedical package, was used to determine the most important variables within each class during model selection.

The criteria used to judge a model as "best" were: (1) check of normality and independence assumptions, (2) check of variables against the physical constraints of the system, (3) R-squared (coefficient of determination), (4) the F value being four times the value of the selected percentage point of the F distribution (Wetz 1966), (5) ease of use of these models, and (6) smallest variance.

The normality assumptions were checked by plotting the dependent variable and the residuals for each model constructed. Plots of observed values versus residuals and predicted values versus residuals were used to check for any predictive faults in the models. Plots of the order of the observation as recorded versus the residuals were used to check for lack of independence. The criterion of Wetz' as discussed in Draper and Smith (1966), "suggests that in order that an equation should be regarded as a satisfactory predictor (in the sense that the range of response values predicted by the equation is substantial compared with the standard error of the response), the observed F ratio (regression mean square)/(residual mean square) should exceed not merely the selected percentage point of the F distribution, but about four times the selected percentage point."[1]

During the model building process many mathematical forms of the variables were screened in order to improve the regression equations. Three of the independent variables, SLO, LDI, and LSLO had quadratic relationships. This was verified with plots of the data and other physical relationships determined from studying the logging system. These three quadratic forms appear in many of the selected models along with various combinations of interaction terms. The following discussion presents a summary of the best model for each element and presents other models which were close contenders.

RESULTS

Five good TT models (fig. 4) were found using the six criteria discussed above. None of the five models violated the normality or independence assumptions. In fact, the plots for each model were quite similar, and no one model could be judged "better" than the others. Since the five models were composed of two dominant variables, DI and LDI, model number one was chosen as the "best" model because of its simplicity:

$$TT = 3.43 + 0.00391DI + 0.0036LDI$$

with an R-squared of 42.69 percent.

Other variables were not included in the final model because they did not have a strong enough influence on the cumulative R-squared. Note that distance and lateral distance are the only variables that are included. Other expected relationships such as number of logs, volume in board feet, weight, and slope were found not to be significant in the total model.

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[1]Draper, N. R., and H. Smith. 1966. Applied regression analysis. p. 64. John Wiley and Sons, Inc: New York, London, Sidney.

Model #1

TT = 3.43 + 0.00391DI + 0.0036LDI

Variable	Cumulative R-squared (%)	Increased in R-squared (%)
DI	30.43	30.43
LDI	42.69	12.26

R^2 = 42.69%, σ^2 = 3.37, F = 58.10, $4(x)F^{.05}$ = 12.28

Model #2

TT = 3.18 + 0.00413DI + 0.0330LDI - 0.95LSLO

Variable	Cumulative R-squared (%)	Increase in R-squared (%)
DI	30.43	30.43
LDI	42.69	12.26
LSLO	43.62	0.93

R^2 = 43.62%, σ^2 = 3.34, F = 39.97, $4(x)F^{.05}$ = 10.72

Model #3

TT = 2.67 + 0.00796DI + 0.1297LDI·SLO^2 - 12.80SLO + 5529.46SLO/DI - 0.000222WT·LSLO

Variable	Cumulative R-squared (%)	Increase in R-squared (%)
DI	30.43	30.43
LDI·SLO^2	40.80	10.37
SLO	43.41	2.62
SLO/DI	47.74	4.32
WT·LSLO	49.08	1.34

R^2 = 49.08%, σ^2 = 3.06, F = 29.49, $4(x)F^{.05}$ = 9.16

Model #4

TT = 7.42 + 0.00424DI + 0.0307LDI - 0.0737WINVEL - 0.0327TEMP - 2.38LSLO^2

Variable	Cumulative R-squared (%)	Increase in R-squared (%)
DI	30.43	30.43
LDI	42.69	12.26
WINVEL	44.35	1.66
TEMP	45.77	1.42
LSLO^2	46.63	0.85

R^2 = 46.63%, σ^2 = 3.20, F = 26.73, $4(x)F^{.05}$ = 9.16

Model #5

TT = 7.59 + 0.00233DI + 0.0289LDI - 0.00282TEMP·WINVEL + 0.000102DI·WINVEL - 4.38LSLO^2

Variable	Cumulative R-squared (%)	Increase in R-squared (%)
DI	30.43	30.43
LDI	42.69	12.26
TEMP·WINVEL	47.08	4.39
DI·WINVEL	51.01	3.94
LSLO^2	53.83	2.81

R^2 = 53.83%, σ^2 = 2.77, F = 35.67, $4(x)F^{.05}$ = 9.16

Figure 4.--Total turn time (TT) statistics

Four of the best TU models (fig. 5) were examined. In each case, none of the models violated the normality assumptions. Again the differences between models were slight. Model number one was chosen as the "best" model since it was an easy model to use and had a relatively high R-squared and F value:

$$TU = - 7.60 + 0.01173DI - 0.01958DI \cdot SLO + 16.01SLO$$

with an R-squared of 61.68 percent. In this model, distance, slope, and distance times slope were important regression predictors of travel unloaded, and these factors are reasonable from a physical standpoint. Other factors such as number of logs and weight were eliminated in the regression analysis, as one would expect, since the carriage is not loaded during the TU element.

Model #1

$TU = - 7.60 + 0.01173DI - 0.01958DI \cdot SLO + 16.01SLO$

Variable	Cumulative R-squared (%)	Increase in R-squared (%)
DI	44.00	44.00
DI•SLO	52.48	8.48
SLO	61.68	9.19

$R^2 = 61.68\%$, $\sigma^2 = 0.37$, $F = 83.17$, $4(x)F^{.05} = 10.72$

Model #2

$TU = 11.21 + 0.00144DI - 36.37SLO + 31.47SLO^2$

Variable	Cumulative R-squared (%)	Increase in R-squared (%)
DI	44.00	44.00
SLO	47.52	3.52
SLO^2	51.57	4.05

$R^2 = 51.57\%$, $\sigma^2 = 0.47$, $F = 55.01$, $4(x)F^{.05} = 10.72$

Model #3

$TU = 12.80 + 0.00150DI - 39.65SLO - 0.0121TEMP + 34.99SLO^2$

Variable	Cumulative R-squared (%)	Increase in R-squared (%)
DI	44.00	44.00
SLO	47.52	3.52
TEMP	51.57	4.05
SLO^2	54.32	2.75

$R^2 = 54.32\%$, $\sigma^2 = 0.45$, $F = 45.77$, $4(x)F^{.05} = 9.8$

Model #4

$TU = - 8.79 + 0.01425DI - 0.02096DI \cdot SLO + 17.98SLO - 0.000022DI \cdot TEMP$

Variable	Cumulative R-squared (%)	Increase in R-squared (%)
DI	44.00	44.00
DI•SLO	52.48	8.48
SLO	61.68	9.19
DI•TEMP	67.94	6.26

$R^2 = 67.94\%$, $\sigma^2 = 0.32$, $F = 81.60$, $4(x)F^{.05} = 9.8$

Figure 5.--Travel unloaded (TU) statistics

It is obvious that for short yarding distances the prediction models can result in unreasonable times. Forcing the models through the origin in order to correct this deficiency was tried but this resulted in significantly lower R-square values and higher variances. Logs were not generally yarded with the balloon system unless they were several hundred feet from the yarder. Therefore, not much data were available for the shorter distances during the model building. As with any regression equation, care should be exercised when using the equation for predictive purposes. Use of short distances should be avoided, especially since they are not normal balloon yarding range.

Of the TLO models built, four were approximately the same in reference to the six criteria (fig. 6). Since they were approximately the same, model number one chosen. It was fairly easy to use and did not depend on the limited temperature (TEMP) and wind velocity (WINVEL) data. The resulting equation:

$$TLO = 0.10 + 0.0123LDI - 0.386LSLO + 0.541LSLO^2 + 0.000073LDI^2$$

has an R-squared of 58.44 percent. Only the first two variables, LDI and LSLO, normally would be included in the model for predictive purposes since the last two variables add little to the cumulative R-squared. Plots of the data and the physical situation, however, showed a definite quadratic relationship with LDI and LSLO. The contribution of the quadratics to the predictive equation is significant only at long lateral yarding distances (LDI) and steep lateral slopes (LSLO). Extension of the data on these variables could be used to verify and refine the model. The variables used in model number one had a physical relationship to the TLO element and were the only variables left after the regression screening process.

The HC variable was found to be best explained by its mean:

HC = 1.01, with a variance of 0.606 as shown below:

Mean	1.01
Median	.70
Variance	.606
Skewness	2.3632.

None of the independent variables were significant predictors of the time required to hook the chokers. The number of logs per turn would normally be expected to affect the time for HC, but in balloon logging, the chokers are preset so that the hooking operation only requires attaching the choker rings to the tagline.

Four satisfactory TL models were found using the six criteria. Model number one (fig. 7) was selected as the "best" model, due to its relative simplicity and lack of dependence on WINVEL:

$$TL = 1.28 + 0.00138DI + 0.0000868WT - 1.151LSLO - 1.626LSLO^2 + 0.00508LDI$$

with an R-squared of 27.86 percent.

Only the first three variables need to be included for predictive purposes; the last two variables ($LSLO^2$ and LDI) add little to the R-squared value. Travel loaded is a function of distance and weight as would be expected. Involvement of lateral slope and lateral distance arise from the first operation in the TL component, wherein the logs are yarded from their position to the side of the skyline before they can be yarded along the skyline. All the independent variables, except distance, contribute relatively small values to the R-squared; however, these additional variables improve the residual plots at the extremes. Hopefully, the R-squared value could be increased by trying the model on a larger range of data from another balloon logging site.

Model #1

$TLO = 0.10 + 0.123LDI - 0.386LSLO + 0.541LSLO^2 + 0.000073LDI^2$

Variable	Cumulative R-squared (%)	Increase in R-squared (%)
LDI	54.12	54.12
LSLO	57.30	3.18
$LSLO^2$	57.86	0.56
LDI^2	58.44	0.59

$R^2 = 58.44\%$, $\sigma^2 = 0.22$, $F = 54.15$, $4(x)F_{.05} = 9.8$

Model #2

$TLO = 0.01 + 0.0184LDI - 0.000173LSLO \cdot LDI^2 + 1.65LSLO^2 - 0.0267LDI \cdot LSLO^2$

Variable	Cumulative R-squared (%)	Increase in R-squared (%)
LDI	54.12	54.12
$LSLO \cdot LDI^2$	57.96	3.84
$LSLO^2$	58.97	1.01
$LDI \cdot LSLO^2$	59.69	0.71

$R^2 = 59.69\%$, $\sigma^2 = 0.22$, $F = 56.99$, $4(x)F_{.05} = 9.8$

Model #3

$TLO = 1.40 + 0.0072LDI - 0.0267WINVEL - 0.0074TEMP + 0.000113LDI^2$

Variable	Cumulative R-squared (%)	Increase in R-squared (%)
LDI	54.12	54.12
WINVEL	61.39	7.27
TEMP	62.67	1.28
LDI^2	64.02	1.34

$R^2 = 64.02\%$, $\sigma^2 = 0.19$, $F = 68.49$, $4(x)F_{.05} = 9.8$

Model #4

$TLO = 0.76 + 0.0090LDI - 0.00033TEMP \cdot WINVEL + 0.0000012LDI \cdot TEMP$

Variable	Cumulative R-squared (%)	Increase in R-squared (%)
LDI	54.12	54.12
TEMP·WINVEL	62.49	8.37
LDI·TEMP	63.81	1.33

$R^2 = 63.81\%$, $\sigma^2 = 0.19$, $F = 91.11$, $4(x)F_{.05} = 10.72$

Figure 6.--Travel laterally out (TLO) statistics

Model #1

$TL = 1.28 + 0.00138DI + 0.0000868WT - 1.151LSLO - 1.626LSLO^2 + 0.005076LDI$

Variable	Cumulative R-squared (%)	Increase in R-squared (%)
DI	16.39	16.39
WT	19.94	3.56
LSLO	24.47	4.52
$LSLO^2$	26.71	2.24
LDI	27.86	1.15

$R^2 = 27.86\%$, $\sigma^2 = 0.75$, $F = 11.82$, $4(x)F^{.05} = 9.16$

Model #2

$TL = 1.63 + 0.00139DI - 0.000268WT \cdot LSLO - 8.14SLO^2 \cdot LSLO^2 + 0.0672LDI \cdot SLO^2 - 0.114LDI^2/DI$

Variable	Cumulative R-squared (%)	Increase in R-squared (%)
DI	16.39	16.39
$WT \cdot LSLO$	22.80	6.41
$SLO \cdot {}^2LSLO^2$	27.14	4.34
$LDI \cdot SLO^2$	29.79	2.65
LDI^2/DI	31.68	1.89

$R^2 = 31.68\%$, $\sigma^2 = 0.71$, $F = 14.19$, $4(x)F^{.05} = 9.16$

Model #3

$TL = 1.61 + 0.00158DI + 0.000087WT - 1.10LSLO - 1.94LSLO^2 - 0.0145WINVEL$

Variable	Cumulative R-squared (%)	Increase in R-squared (%)
DI	16.39	16.39
WT	19.94	3.56
LSLO	24.47	4.52
$LSLO^2$	26.71	2.24
WINVEL	27.96	1.25

$R^2 = 27.96\%$, $\sigma^2 = 0.75$, $F = 11.88$, $4(x)F^{.05} = 9.16$

Model #4

$TL = 1.81 + 0.00205DI - 0.000157WT \cdot LSLO - 0.0361TEMP \cdot SLO^2 - 0.00051TEMP \cdot WINVEL + 0.06535WT/DI$

Variable	Cumulative R-squared (%)	Increase in R-squared (%)
DI	16.39	16.39
$WT \cdot LSLO$	22.80	6.41
$TEMP \cdot SLO^2$	27.47	4.67
$TEMP \cdot WINVEL$	30.78	3.31
WT/DI	33.46	2.69

$R^2 = 33.46\%$, $\sigma^2 = 0.70$, $F = 15.39$, $4(x)F^{.05} = 9.16$

Figure 7.--Travel loaded (TL) statistics

The unhook chokers model was found to be best explained by its mean:

UC = 0.88, with a variance of 0.323

as shown below:

Mean	0.88
Median	.70
Variance	.323
Skewness	2.8166.

None of the independent variables were found to be significant predictors of this component, probably because of the highly variable conditions and locations of the log decks.

CONCLUSIONS

An alternate method of predicting total turn time (TT') was formed by summing the component models:

TT' = TU + TLO + HC + TL + UC.

The "best" component models for TU, TLO, and TL were used to predict the time required for these factors. Time required for HC and UC was estimated using their mean values. The correlation between the summed component predictors and the observed data was calculated and then squared. This psuedo R-squared was 0.4264; the standard error of the predicted values was 1.829. These statistics for TT' were then compared with TT model number one (fig. 4) which had an R-squared of 0.4269 and standard error of 1.836. Since the additive model built from the components was more complex than the TT model, it was concluded that the TT model was the best total turn time model for this study. The similarity of the two sets of statistical values indicates that the models were properly selected for both the components and the total turn.

As a final check, the TT model was tested using 15 observations which had been randomly selected prior to the analysis and set aside for this purpose. The psuedo R-squared (defined in the same way as in the preceding paragraph) was 0.4262, and the standard error was 1.837. These agree very well with the statistics for the best TT model. This implies that the model is doing a reasonable job of predicting the response variable, total turn time.

The variables in the models developed in this analysis do not explain as much as the variation in the dependent variables as was initially expected. The R-squared values for the dependent variables were: 42.69 percent for TT, 61.68 percent for TU, 58.44 percent for TLO, and 27.86 percent for TL. The authors feel that a more quantitative method of rating the coded independent variables would increase the R-squared values. This conclusion was based on observations made over a wide range of conditions as compared to the conditions encountered during the relatively short stay of the time study crew. The models also could be improved by expanding the range of the independent variables. This would require many more observations, however, because of the number of combinations of variables and the possibility of interactions between the variables.

There are other possible sources of error in the equations which would be obvious to anyone who has worked or studied logging operations, but those presented are felt to be most important.

There are intangible human factors that affect operator and logging crew efficiency on a daily basis. The data from this study easily could have been influenced by the method logging crews were paid. Payment strictly for the number of hours worked gives little incentive to increase production. Payment based on production (i.e., logs yarded/day or MBF/day) tends to increase production as long as the rates are fair. On the balloon logging job, payment was on an hourly basis plus a bonus for each log yarded above a daily quota. This sounds like a satisfactory method of payment and it did work well most of the time. Occasional difficult logging conditions, however, made it extremely difficult for the crew to surpass their daily quota no matter how hard they worked. This tended to discourage the crew and production decreased. At the other extreme, under ideal logging conditions the crew could greatly surpass their daily quota. The crew would then produce enough logs to receive a bonus, but not enough so that the company raised their quota for bonus pay. The problem of how to set quotas could be aided by time and motion studies such as this.

The statistics for the various models provide basic information about the relative importance of various factors for those studying balloon logging operations. The regression equations serve as guidelines for predicting time required to complete various portions of the balloon logging cycle. Persons using the equations should familiarize themselves with balloon logging and keep in mind the limitations of the equations that have been presented here.

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Hartsog, William S., and James Cass.
1979. Statistical analysis of balloon logging time and motion data. USDA For. Serv. Res. Pap. INT-239, 15 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Time and motion studies were conducted on an experimental balloon logging show in the Idaho Batholith during 1973. Selected variables were divided into three classes: those involving the time required for each portion of the logging cycle, factors directly related to the yarding operation, and independent variables. Variables were then partitioned into four groups so that easy comparisons could be made between predictive models. The resulting regression equations serve as limited guidelines for predicting time requirements for the various portions of the balloon logging cycle.

KEYWORDS: logging--time and motion study, aerial logging, balloon logging.

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